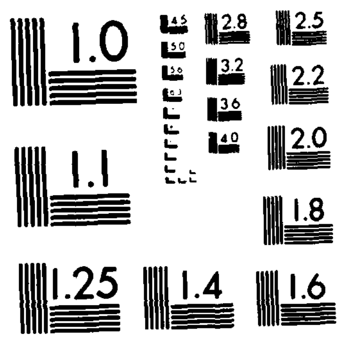
AD-A143 796 SIGNAL DETECTION IN MULTIPLE-ACCESS CHANNELS(U) 1/1
ILLINOIS UNIV AT URBANA COORDINATED SCIENCE LAB
H V POOR 18 JUL 84 ARO-17761.15-EL DAAG29-81-K-0062

UNCLASSIFIED F/G 17/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

ARO 17761.15-EL

(2)

AD-A143 796

SIGNAL DETECTION IN MULTIPLE-ACCESS CHANNELS

Final Report

by

H. Vincent Poor, Principal Investigator

July 18, 1984

U. S. ARMY RESEARCH OFFICE

Contract DAAG 29-81-K-0062

Coordinated Science Laboratory
University of Illinois at Urbana-Champaign

Approved for Public Release;
Distribution Unlimited

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARO 17761.15-EL	2. GOVT ACCESSION NO. AD-A143796	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SIGNAL DETECTION IN MULTIPLE-ACCESS CHANNELS		5. TYPE OF REPORT & PERIOD COVERED Final - May 21, 1981-May 20, 1984
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) H. Vincent Poor		8. CONTRACT OR GRANT NUMBER(s) DAAG 29-81-K-0062
9. PERFORMING ORGANIZATION NAME AND ADDRESS Coordinated Science Laboratory University of Illinois at Urbana-Champaign 1101 W. Springfield Avenue, Urbana, IL 61801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office Post Office Box 12211 Research Triangle Park, NC 27709		12. REPORT DATE July 18, 1984
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA

18. SUPPLEMENTARY NOTES

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

signal detection, multi-user communications, robust matched filters, optimum detection in multi-access noise

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes research efforts performed under the support of U.S. Army Research Office Contract DAAG 29-81-K-0062. The period of this contract was May 21, 1981-May 20, 1984.

PROJECT SUMMARY

ARO CONTRACT DAAG 29-81-K-0062

(May 21, 1981-May 20, 1984)

The overall purpose of this research project was to seek new methods for improving the robustness and efficiency of multiple-user communications systems. The principal approach used was to consider the multiple-user communications problem from the viewpoint of signal detection theory, which focuses attention on the analysis and optimum design of receivers. There are two general aspects to this problem that are of interest:

1.) existing systems can be analyzed under a variety of nonideal, but realistic, conditions to determine where improvement is needed;

and 2.) new designs can be sought for situations on which existing systems are unsuitable and/or are subject to considerable improvement.

During the course of this study, a variety of research problems have been considered within this general context. Also, several related research results have been obtained as by-products of the central research efforts. These results are reported in detail in the papers listed in the accompanying publications list. The nature of these various results is described briefly in the following paragraphs, with reference given to the relevant papers in which details can be found.

One of the principal areas of study conducted during this effort was concerned with the problem of robust matched filtering. Matched filters are the principal elements in most conventional multi-user receivers, although they are optimum only in the well-modeled single-user context. Robust matched filters are detection filters designed to exhibit performance insensitivity to modeling inaccuracies and uncertain distortion, which may be caused by effects such as jamming, other-user noise, channel nonlinearity, timing jitter, etc. Several aspects of the robust matched filtering problem were considered during the course of this project. In [5], a general formulation of this problem was introduced which (by using a Hilbert-space model) allowed for the simultaneous treatment of many matched filtering situations. This methodology was treated in the context of digital communications applications in [5] and in [2], [14] and [15]. These papers include optimum (robust) filter designs and performance analysis for several useful models of channel distortion and noise uncertainty. Also the problem of designing optimum signals to combat channel distortion was treated in [17] and [18]. Finally, a survey of this methodology was presented in [3].

The primary method used in the development of robust matched filtering was a game theoretic formulation in which the design objective is to maximize the worst-case signal-to-noise ratio (SNR). Although, generally speaking, minimax strategies can sometimes be conservative, this approach led to quite efficient and robust procedures in the matched filtering problem. Because of this successful application in matched filtering, the methods of [5] were extended to a general class of robust filtering and detection problems in [6], [13], and [16]. This general methodology was studied in the contexts of a variety of applications including quadratic detection [16,19], MMSE filtering [16], output-energy filtering [16], Kalman-Bucy filtering and prediction [12], and LQG regulation of linear systems [12].

The second principal area of research conducted during this project dealt with the problem of optimum receiver design for binary signalling in the presence of Gaussian white noise plus multi-user noise. This work differs from the robustness approach discussed in the above paragraphs in that, here, the specific structure of the multi-user noise is exploited to improve performance. One of the main incentives for the study of optimum multi-user detectors is that the demodulation methods employed in practice are limited to single-user detection systems and hence the signal constellation carries the entire burden of complexity required to achieve a given performance level. The results of this study, reported in [8], [9], [10], and [11], show that the proposed multi-user detectors afford important performance gains over conventional single-user systems.

It is shown in [8-11] that optimum coherent demodulation of K-user asynchronous signals requires the observation of the whole received waveform to produce a sufficient statistic for any symbol decision. Furthermore, since the transmitted symbols are not independent conditioned on the received waveform, decisions can be made according to two different optimality criteria, namely selection of the sequence of symbols that maximizes the joint a-posteriori distribution (globally optimum sequence detection) or the sequence of a-posteriori marginal distributions (minimum probability of error). In both cases the optimum receiver processes the received signals via a bank of K single-user matched filters followed by a dynamic programming decision algorithm. A question of primary interest for the use of the optimum K-user detector in large-scale problems is the computational complexity of the decision algorithm. On one hand, we have shown that the minimum time-complexity per binary decision of a detector based on a dynamic programming algorithm is $O(S|A|^K/K)$ where $|A|$ and S are equal to the alphabet-size and the number of clusters of synchronized users respectively. On the other hand we have proved that, given the signal crosscorrelations, the problem of (synchronous or asynchronous) optimum multi-user detection is NP-hard in the number of users.

Performance analysis of the proposed detectors is achieved through various bounds which together provide tight approximations for all noise levels. In the low SNR region the error probabilities of the single-user detector with and without interfering users are tight upper and lower bounds respectively to the minimum error probability. We have derived an upper and a lower bound which differ in the moderate-to-high SNR region by a multiplicative parameter independent of the noise level which is typically close to unity. The upper bound is achieved through the introduction of various subsets of error sequences that depend on the noise realization and through the notion of decomposability of a sequence which captures the essential property needed for the establishment of a tight bound. On the other hand, the lower bound is obtained by analyzing a receiver with side-information that reduces the detection problem to K $|A|$-ary hypothesis-testing problems. The fact that the above bounds are tight and have the same asymptotic behavior as that of a single-user system allows us to define the k^{th}-user asymptotic efficiency as the ratio between the single-user signal energy required to achieve the same error probability and the actual signal energy when the noise level vanishes. It turns out that the set of K-user asymptotic efficiencies emerge as the parameters that determine performance for all practical purposes in the SNR region of usual interest. Moreover, the globally optimum sequence detector, although not optimum in terms of error probability, attains the maximum asymptotic efficiency. We have shown that nontrivial signal sets result in nonzero asymptotic efficiencies, a property that is not shared by other suboptimum receivers such as the conventional single-user detector. The import of this fact is that while conventional systems can become multiple-access limited even in the absence of additive noise, any prespecified probability of error is achievable using the optimum detector. Several sufficient conditions on the energies and cross-correlations of the signal constellation have been shown to guarantee unit asymptotic efficiencies (i.e., no degradation due to the presence of other asynchronous users). Such sufficient conditions impose very mild requirements on the quality of the signal set, and they are satisfied by signature sequences commonly used in Direct-Sequence Spread-Spectrum multiple-access systems. Analytical expressions of the maximum asymptotic efficiencies have been shown in the case of 2 active users, and a combinatorial algorithm for their numerical computation has been obtained. These results have been applied to the investigation of the near-far problem (i.e., the effects of unequal received signal energies) which in practice is one of the main sources of performance loss for the conventional detector. It has been shown that as the power of the interfering users increases, the asymptotic efficiency of the optimum detector becomes unity, while the probability of error of the conventional detector suffers very quick degradation. A robustness assessment of the proposed detectors under unmodeled interference (such as jamming or additional multiple-access noise) shows that, even though moderate crosscorrelation properties often result in unit asymptotic efficiencies, a further improvement of the signal design provides the same degree of robustness as that achievable in the absence of interfering users.

In addition to the major efforts on the problems of robust matched filtering and optimum multi-user detectors, a study of the effects of dependent (i.e., colored) and nonGaussian noise on multi-user communication systems was initiated. Our work in this area is reported in [1] and [4] and, although of a preliminary nature, the results here indicate that both of these factors can significantly degrade system performance beyond that predicted by the conventional white-noise model. This indicates a need for further consideration of these issues since such nonideal effects are often present in the multi-user environment, particularly in such systems as mobile radio networks.

PUBLICATIONS REPORTING RESEARCH SUPPORTED BY ARO CONTRACT DAAG-29-81-K-0062 (May 21, 1981-May 20, 1984).

1. B. Aazhang and H. V. Poor, "NonGaussian Effects in DS/SSMA Communications," Proceedings of the 1984 IEEE Military Communications Conference, Los Angeles, CA, October 21-24, 1984 (to appear).

2. C. J. Alston, "Analysis of Maximin Matched Filter Design for Communication Through a Nonlinearly Distorting Channel," Coordinated Science Laboratory Technical Report No. R-930, University of Illinois at Urbana-Champaign, Urbana, IL, December 1981.

3. S. A. Kassam and H. V. Poor, "Robust Signal Processing for Communication Systems," IEEE Communications Magazine, Vol. 21, No. 1, pp. 20-28, January 1983.

4. T. W. Miltonberger, "Direct-Sequence Spread-Spectrum Detectors in Colored Gaussian Noise," M.S. Thesis, Department of Electrical Engineering, University of Illinois at Urbana-Champaign, June 1983.

5. H. V. Poor, "Robust Matched Filters," IEEE Transactions on Information Theory, Vol. IT-30, No. 5, pp. 677-687, September 1983.

6. S. Verdú, "A General Approach to Minimax Robust Filtering," M.S. Thesis, Department of Electrical Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, November 1981. [Also published as Coordinated Science Laboratory Technical Report No. R-933, December 1981.]

7. S. Verdú, "Comments on 'Anamalous Behavior of Receiver Output SNR as a Predictor of Signal Detection Performance Exemplified for Quadratic Receivers and Incoherent Fading Gaussian Channels'," IEEE Transactions on Information Theory, Vol. IT-28, No. 6, pp. 952-953, November 1982.

8. S. Verdú, "Minimum Probability of Error for Asynchronous Multiple Access Communication Systems," Proceedings of the 1983 Military Communications Conference, Washington, D. C., October 31-November 2, 1983, pp. 213-219. [Also to appear in IEEE Transactions on Information Theory.]

9. S. Verdú, "On Fixed-Interval Minimum Symbol Error Probability Detection," Coordinated Science Laboratory Technocal Report R-990 (UILU-ENG83-2211), University of Illinois at Urbana-Champaign, June 1983.

10. S. Verdú, "Optimum Multi-User Signal Detection," Ph.D. Dissertation, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, August 1984 (tentative date).

11. S. Verdú, "Optimum Sequence Detection of Asynchronous Multiple-Access Communications," Abstracts of Papers: 1983 International Symposium on Information Theory, St. Jovite, Quebec, September 26-30, 1983, p. 80.

12. S. Verdú and H. V. Poor, "A General Approach to Estimation and Control of Linear Systems with Uncertain Statistics," Proceedings of the Sixteenth Annual Conference on Information Sciences and Systems, Princeton University, Princeton, NJ, March 17-19, 1982, pp. 330-355.

13. S. Verdú and H. V. Poor, "General Results on Minimax Robust Filtering," Abstracts of Papers: 1982 International Symposium on Information Theory, Les Arcs, France, June 21-25, 1982, p. 124.

14. S. Verdú and H. V. Poor, "Least Favorable Signals and Noise for Discrete-Time Robust Matched Filters," 1981 IEEE National Telecommunications Conference, Conference Record, New Orleans, LA, November 30-December 3, 1981, pp. D8.2.1-D8.2.5.

15. S. Verdú and H. V. Poor, "Minimax Robust Discrete-Time Matched Filters," IEEE Transactions on Communications, Vol. COM-31, No. 2, pp. 208-215, February 1983.

16. S. Verdú and H. V. Poor, "On Minimax Robustness: A General Approach and Applications," IEEE Transactions on Information Theory, Vol. IT-31, No. 2, pp. 328-340, March 1984.

17. S. Verdú and H. V. Poor, "Optimum Signal Design for Communication Through Uncertain Distorting Channels," Proceedings of the Seventeenth Conference on Information Sciences and Systems, The Johns Hopkins University, Baltimore, MD, March 23-25, 1983, pp. 222-227.

18. S. Verdú and H. V. Poor, "Signal Selection for Robust Matched Filtering," IEEE Transactions on Communications, vol. COM-31, pp. 667-670, May 1983.

19. S. Verdú and H. V. Poor, "Some Minimax Detection and Estimation Problems in a Hilbert Space Setting," Proceedings of the 22nd IEEE Conference on Decision and Control, San Antonio, TX, December 14-16, 1983, pp. 292-297.

SCIENTIFIC PERSONNEL SUPPORTED BY ARO CONTRACT DAAG29-81-K-0062 (May 21, 1981-May 20, 1984).

H. Vincent Poor, Principal Investigator

Behnaam Aazhang, Graduate Research Assistant
Thomas W. Miltonberger, Graduate Research Assistant
Sergio Verdú, Graduate Research Assistant
Richard K. Wolf, Graduate Research Assistant

ADVANCED DEGREES EARNED BY ABOVE PERSONNEL

B. Aazhang (M.S. in Electrical Engineering, 1982; Ph.D. in Electrical Engineering, expected 1985).

T. W. Miltonberger (MS. in Electrical Engineering, 1983).

S. Verdú (M.S. in Electrical Engineering, 1981; Ph.D. in Electrical Engineering, expected August 1984).

R. K. Wolf (M.S. in Electrical Engineering, expected August 1984).